Explore mechanisms behind the spring to summer drought memory and their application for early warning of summer drought over US Southern Plains

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Research Questions:

- ***Why do some La Niñas lead to summer droughts, whereas others do not?***

- ***Is there spring to summer drought memory? If so, how important is such memory in determining the summer drought? what process is responsible for such a drought memory?***

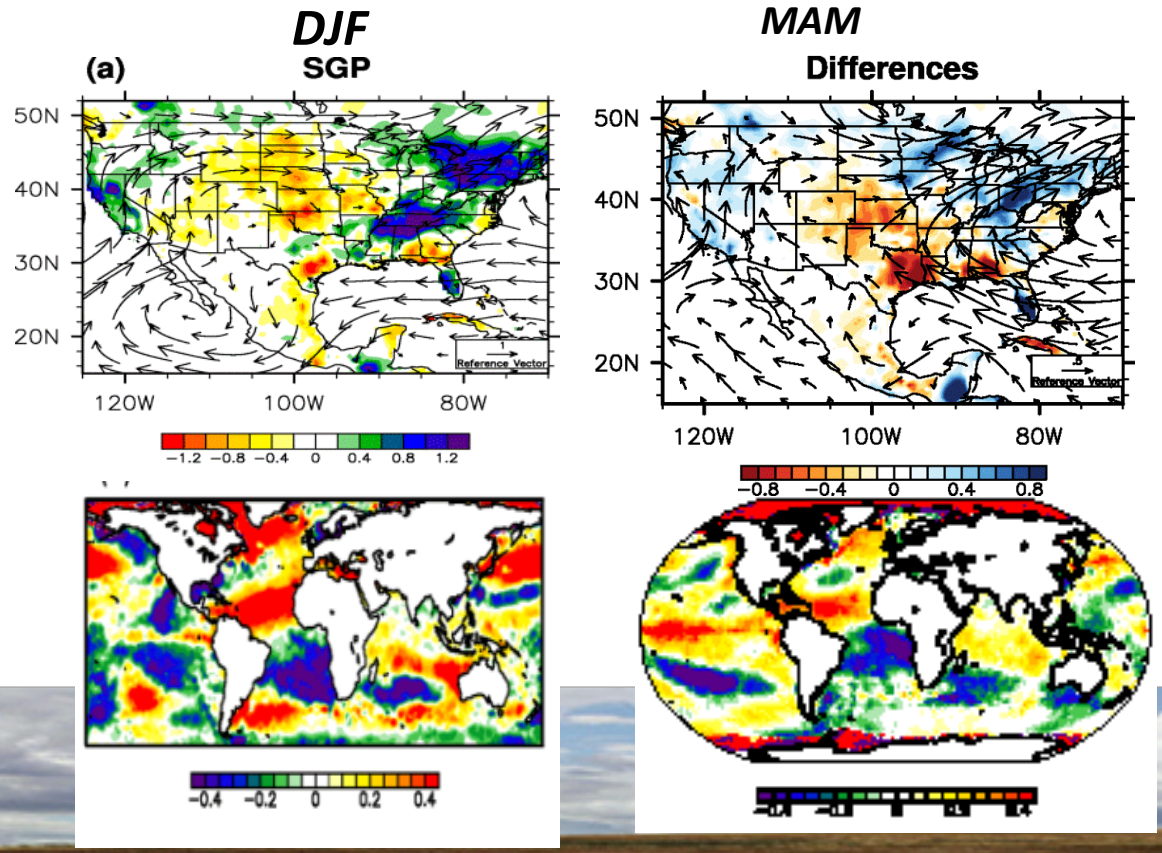
- ***Is it possible to provide an early warning of the summer drought based anomalous large-scale atmospheric and land surface conditions in spring?***

Datasets:

- North American Regional Reanalysis (NARR), soil moisture, 0.25 by 0.25 degree, daily, from, 3hourly from Jan. 1979-Dec. 2013, about 32 km resolution.
- NCEP/NCAR reanalysis1 fields, 2.5 by 2.5 degree, monthly from Jan.1948-Dec. 2013
- CRU TS3.21 precipitation, 0.5 by 0.5 degree, monthly from Jan. 1901- Dec. 2012
- Essential Climate Variable (ECV) soil moisture data
- Merged product from blending active and passive soil moisture products, derived from SMMR, SSM/I, TMI and ASMR-E , AMI-WS and ASCAT
- CFSR (1982-2010)+CFSV2 realtime Mar 2011-Dec 2012
- IRI Analyses SPI SPI-CAMSOPI_6-Month

- **Why do some La Niña events lead to summer droughts whereas other do not?**

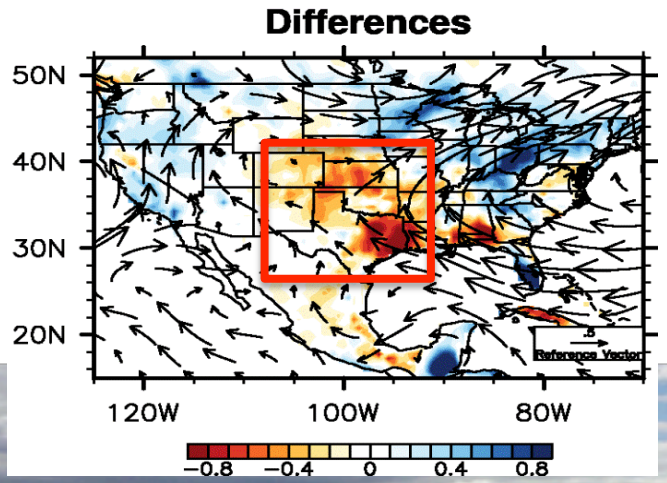
- **La Niñas associated with summer droughts over SGP show a stronger low-level anticyclonic circulation over SC and SE US and warm SSTA in the N. Atlantic in DJF and MAM.**

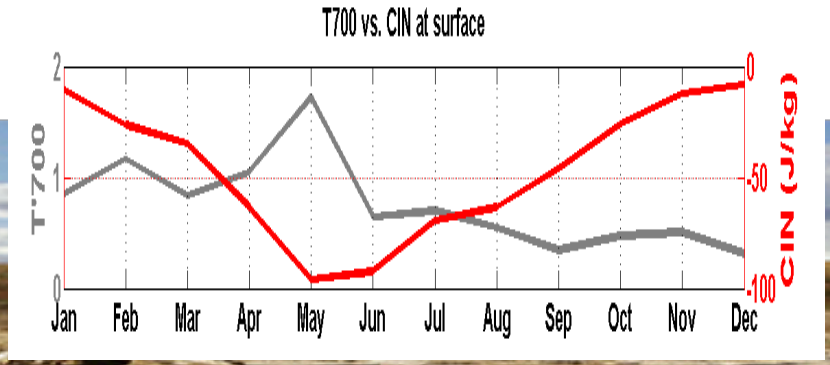


Composite differences of the 700 hPa Z' and SSTA between La Niñas with subsequent summer droughts (3) and the La Niñas without summer droughts (15) over SGP for the period of 1950-2013

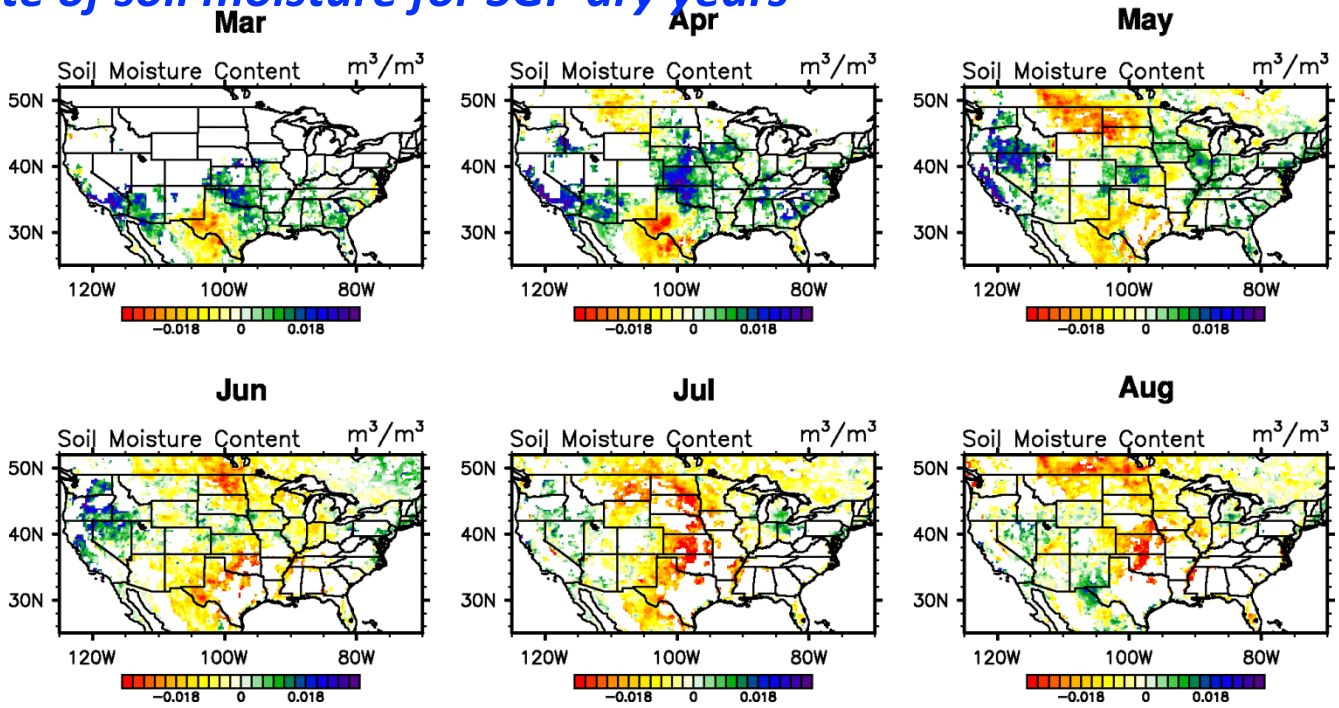
The influence of the anomalous anticyclonic circulation on convection

- **Rainfall source changes from extratropical synoptic disturbances to tropical thermodynamic driven convection during spring over SGP.**
- **Anomalous subsidence increase of T700hPa and CIN. The latter suppresses onset of tropical thermodynamic driven convection.**

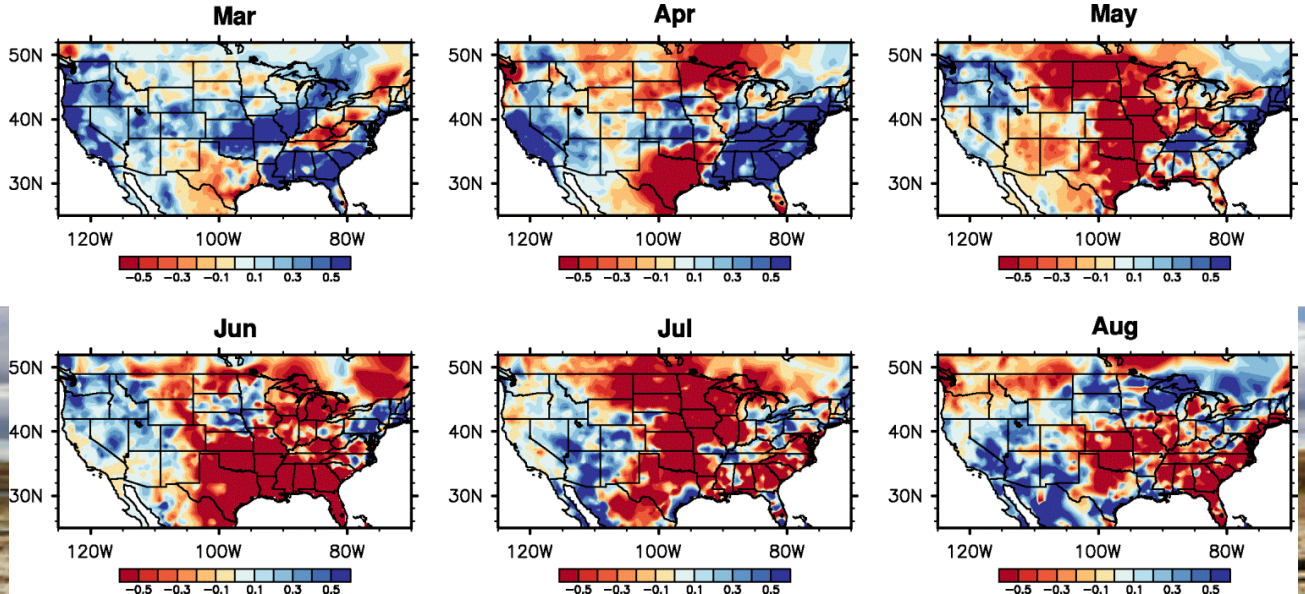




- *Composite of soil moisture for SGP dry years*



- *Composite of rainfall (mm/day) for SGP dry years*

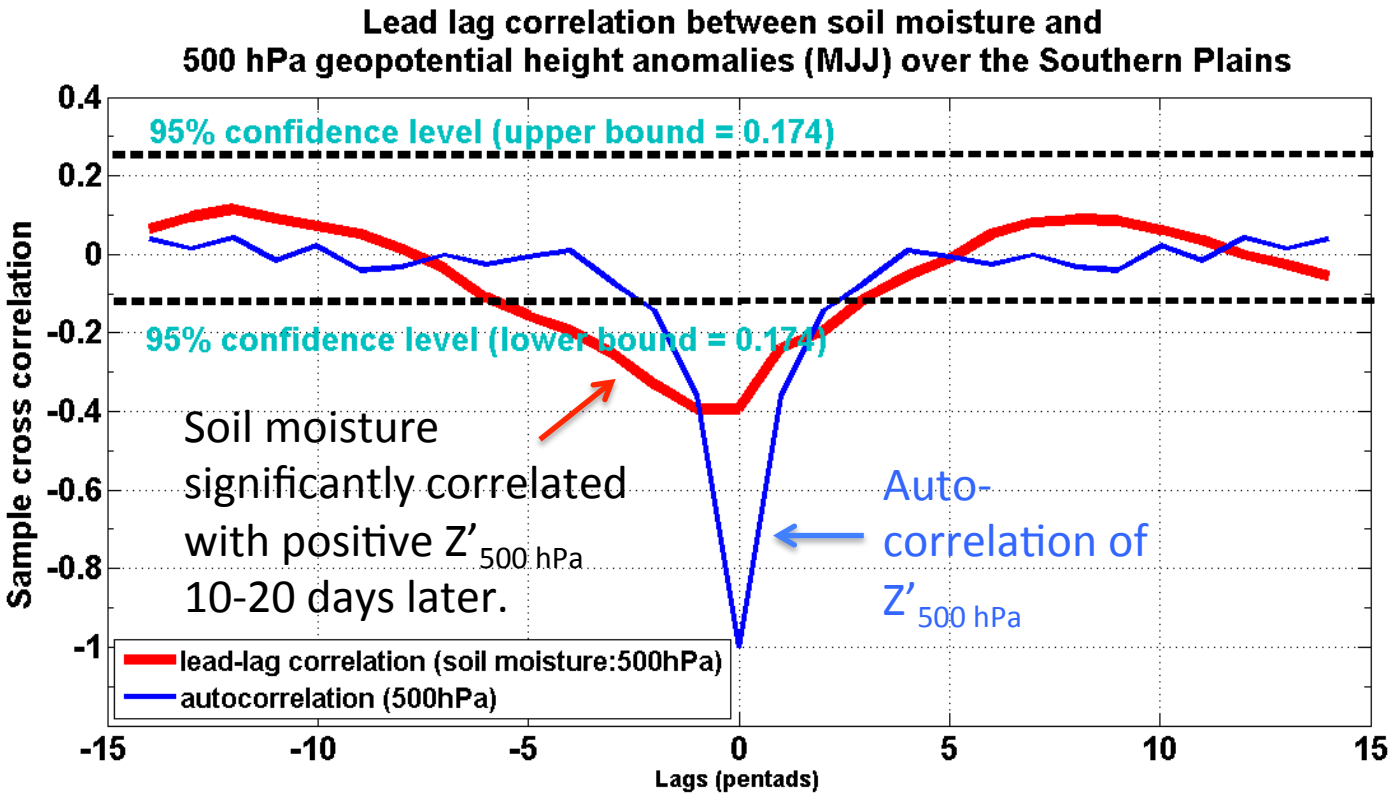


Is there spring to summer drought memory?

- **Observations show that 13 out of 16 severe-to-extreme summer droughts over the SC US since 1895 are linked to dry spring. Only two springs (drought years of 1971 and 1996) are not followed by a dry summer.**
- **On the other hand, dynamic models cannot maintain the initial dry soil moisture anomalies in spring for more than 2 months.**

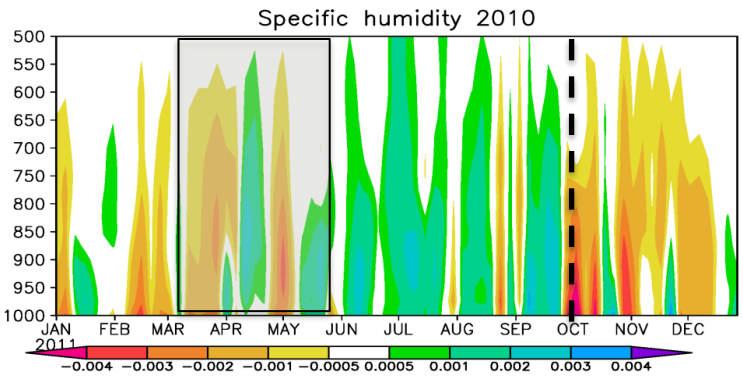
What mechanisms could maintain or re-enforce dry soil moisture memory from spring to summer?

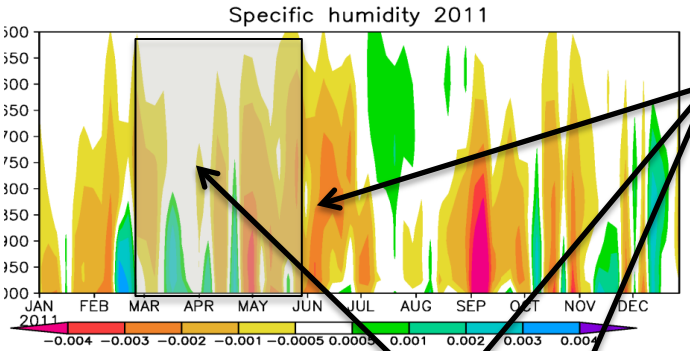
Could dry soil moisture anomalies re-enforce anomalous mid-tropospheric high?



- Lack of deep convection in spring appears to set stage for summer dryness.

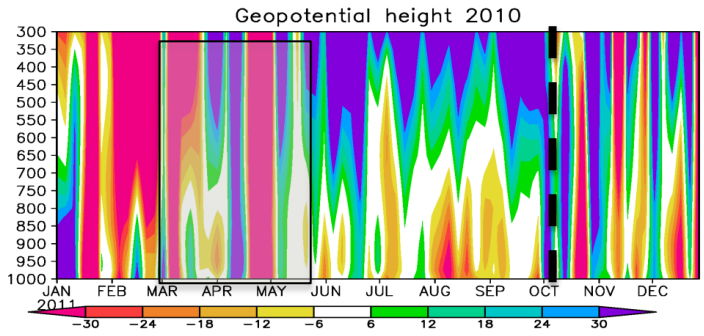
Specific humidity anomaly (kg/kg) for 2010-2011

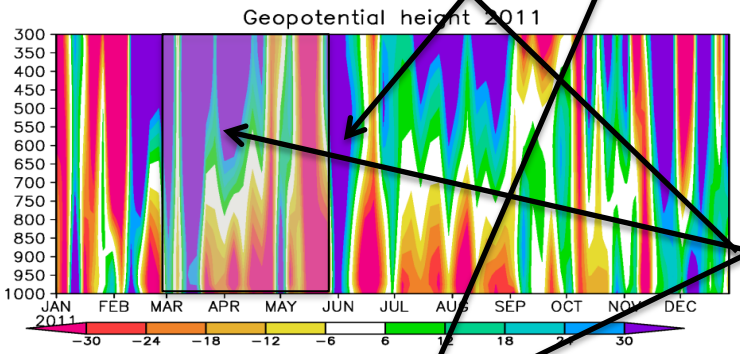




Deep cyclonic system in early summer did not lead to strong deep convection presumably due to spring dryness

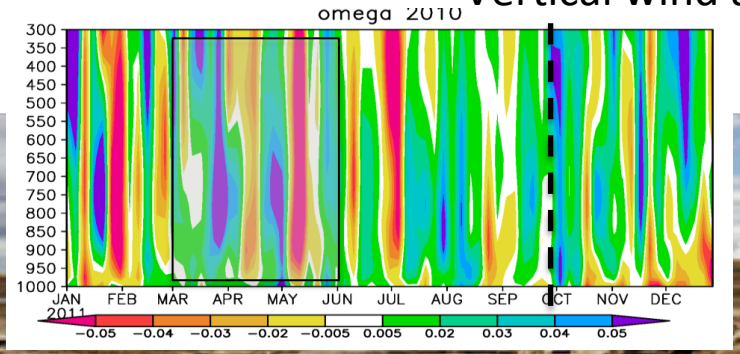
Geopotential height anomaly (gpm)

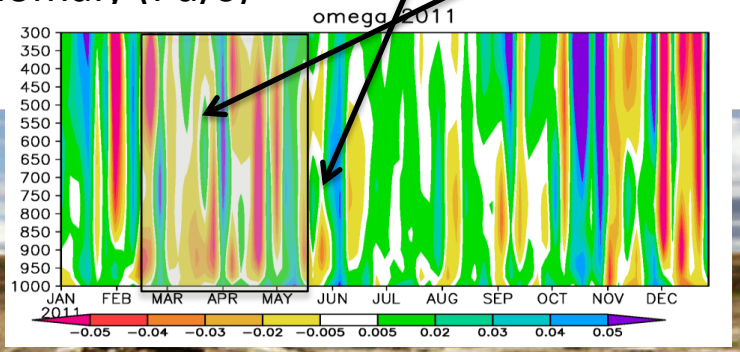




Persistent low-mid tropospheric high anomaly may suppress spring deep convection

Vertical wind anomaly (Pa/s)

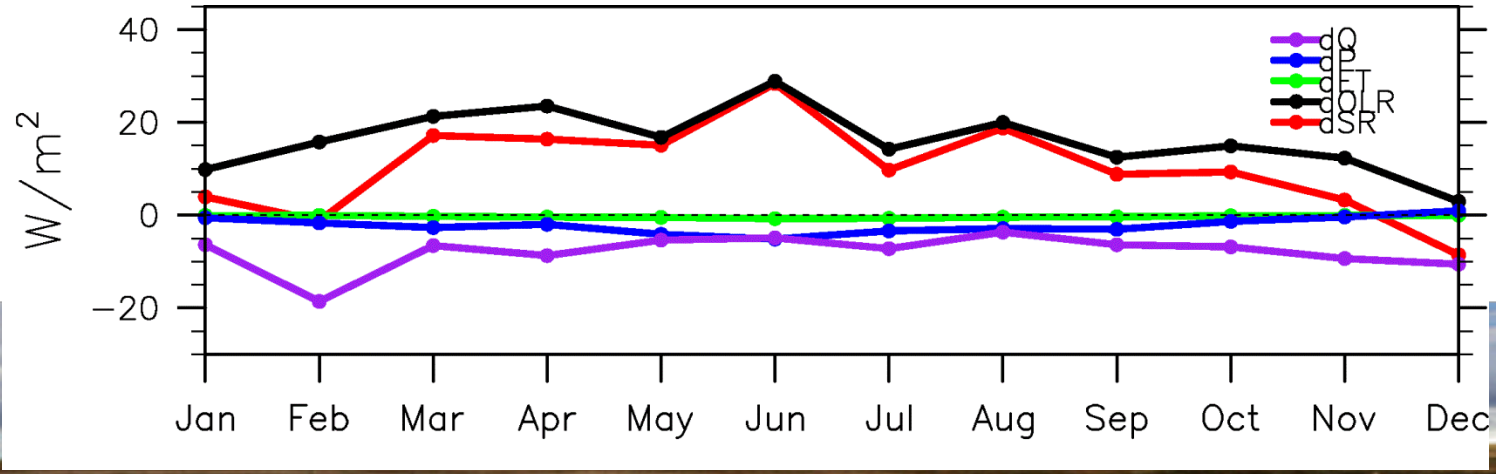




How does spring dryness influence large-scale circulation?

- **The negative diabatic heating anomalies in 2011 is mainly contribute by increasing radiative cooling (OLR) due to decrease of cloudiness and atmospheric humidity in Jan-Apr, by decrease of latent heating of rainfall in May and June.**
-

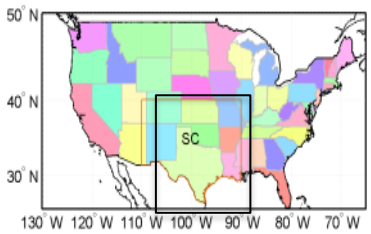
dQ in 2011 calculated from NARR and NCEP/NCAR reanalyses

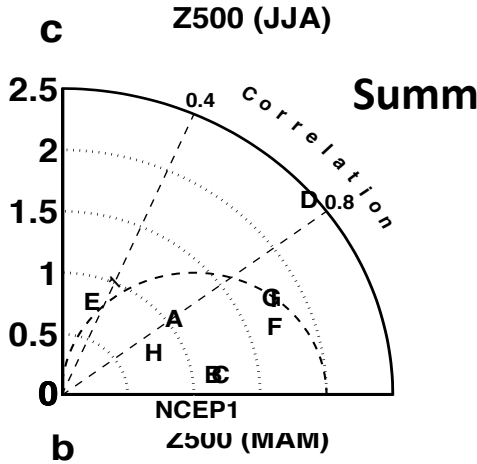


Is it possible to provide an early warning of the summer drought based anomalous large-scale atmospheric and land surface conditions in spring?

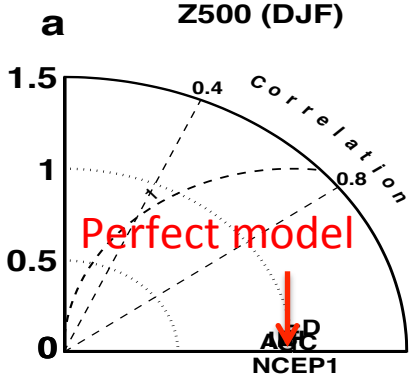
Challenges for seasonal prediction of summer drought:

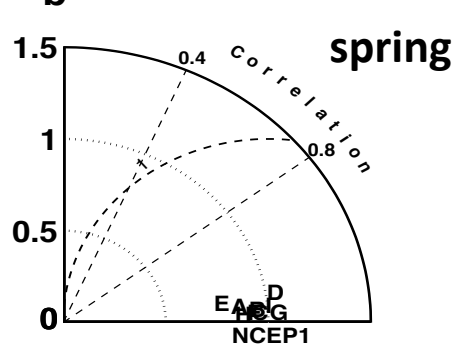
- Seasonal forecast unable to predict major summer droughts in recent years, and does not show more skill than autocorrelation (Guan et al. 2012; Hoerling et al. 2013).
- Current (CMIP5) climate models have large uncertainty in simulating summer rainfall, and large scale circulation over US Southern Great Plains (SGP).
- **Can we use dynamic prediction in winter and spring and empirical model to predict summer drought?**





Winter:





Fu et al. 2014

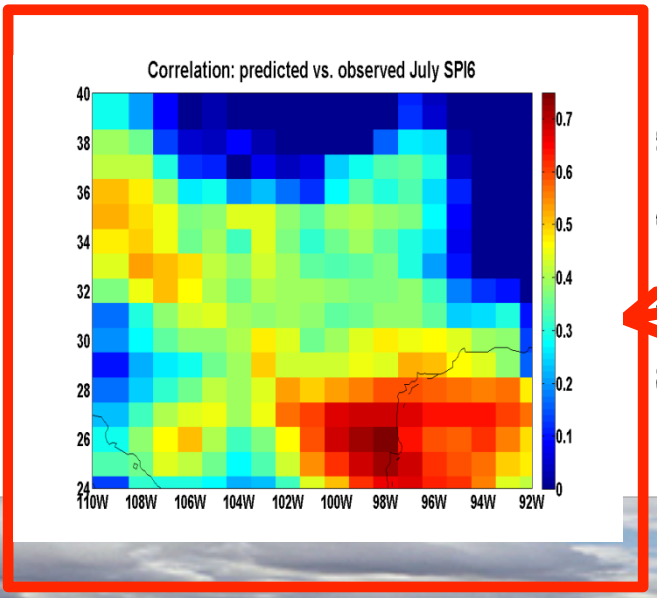
Statistical model

1. First run a Multivariate EOF analysis on the three predictor variables
   a. *April z'500 hPa CFSR*
   b. *April CIN proxy (T700-Tdsurf) from CFSR*
   c. *April soil moisture CFSR*
2. Retain first two EOF modes accounting for ~90% of variance for rotation. Input the two rotated EOF modes as predictor variables to a Canonical Correlation Analysis to predict July SPI6. Use the Climate Predictability Tool (CPT) developed at IRI to run CCA.
3. 24-year training period (1/3 left for validation). 3-year cross-validation window. Model fitted with cross-validated error variance. 1982-2005 as climatological period.

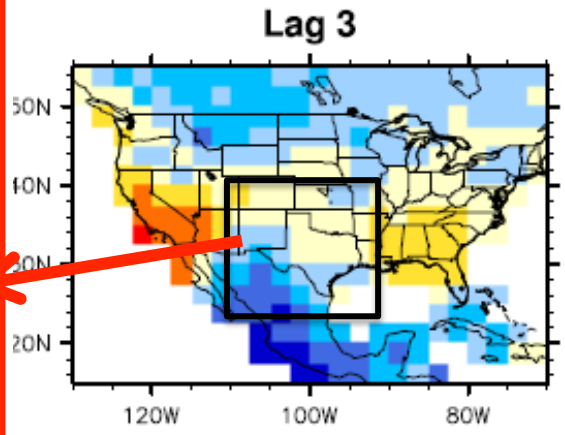
Drought early warning indicator shows higher skill than the baseline and the dynamic prediction

Drought indicator skill comparison: Spearman's correlation (obs vs. pred)

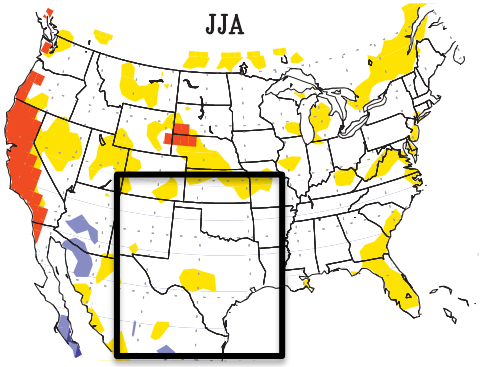
Correlation between observed and predicted July SPI6

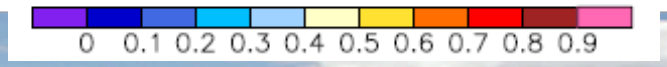


Baseline, autocorrelation of the observed SPI6, Lyon et al 2012

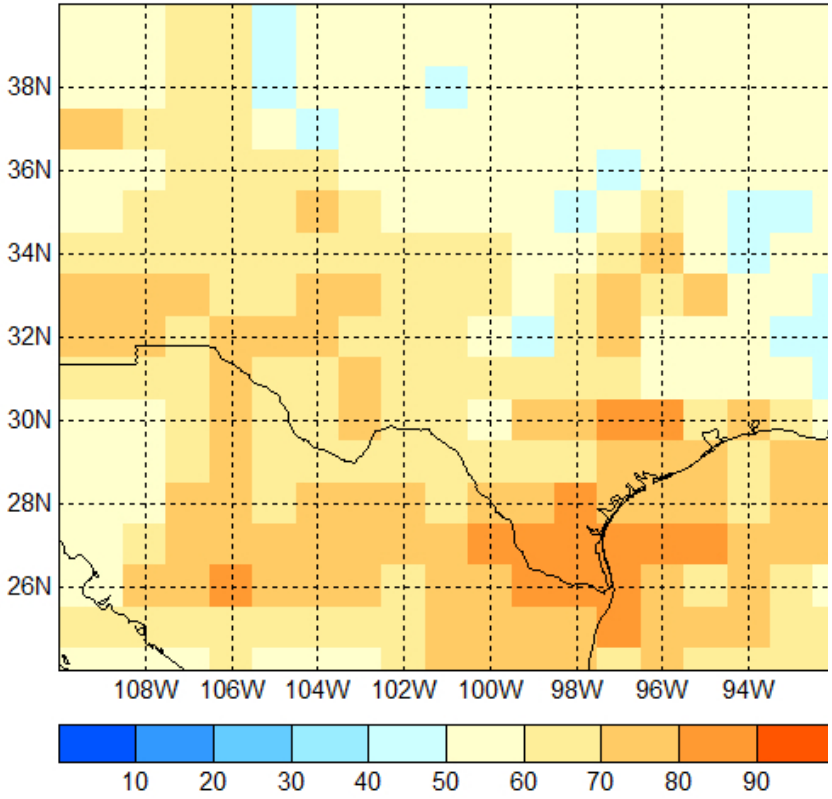


NOAA CFSV2 Dynamic prediction, Quan et al 2012

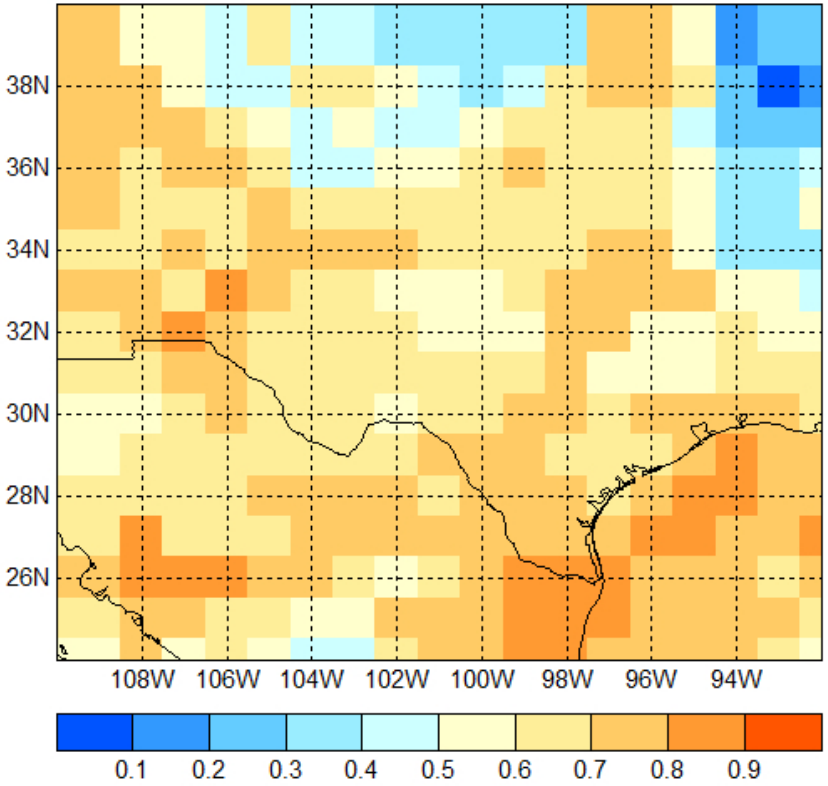




2AFC (forecast categories) for drought indicator



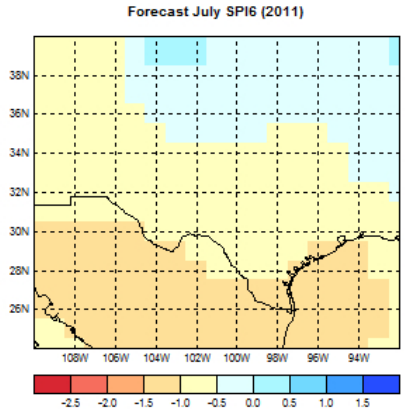
ROC Area (Below-Normal) for drought indicator



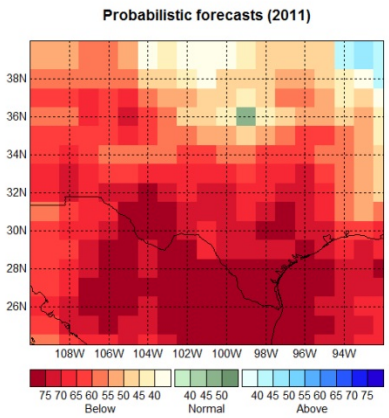
Hindcasts qualitatively capture the general pattern of the 2011 and 2013 summer drought

July 2011 predicted

SPI6 actual values

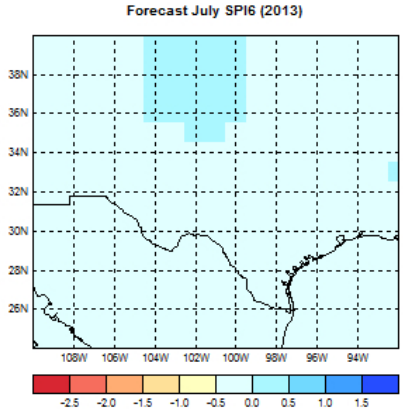


SPI6 probabilistic

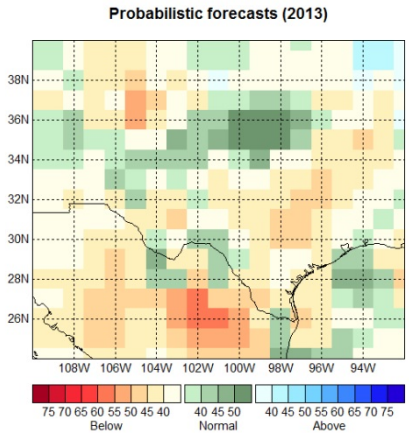


July 2013 predicted

SPI6 actual values

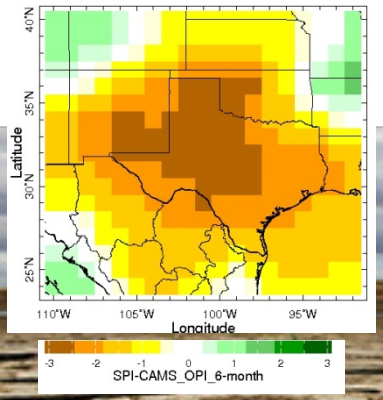


SPI6 probabilistic

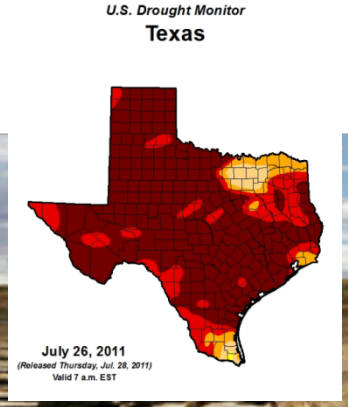


July 2011 observed

Observed SPI6

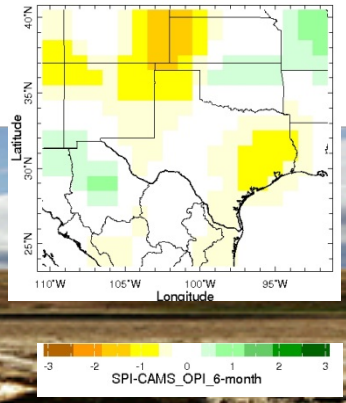


Drought Monitor 07/11

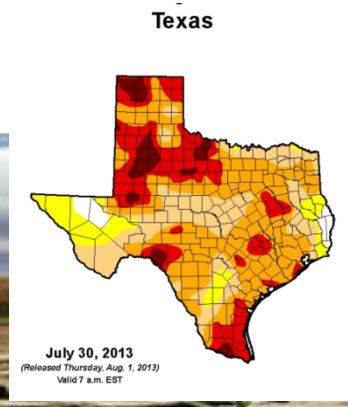


July 2013 predicted

Observed SPI6

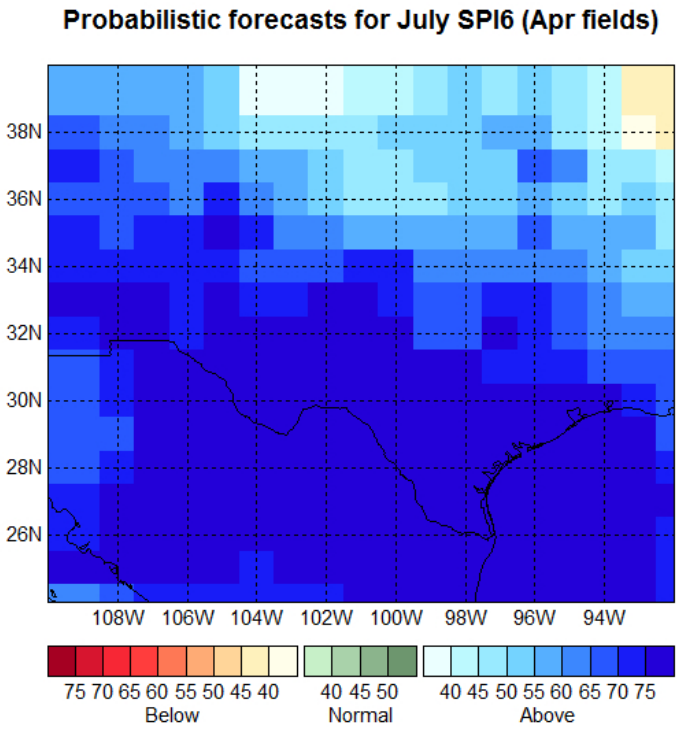


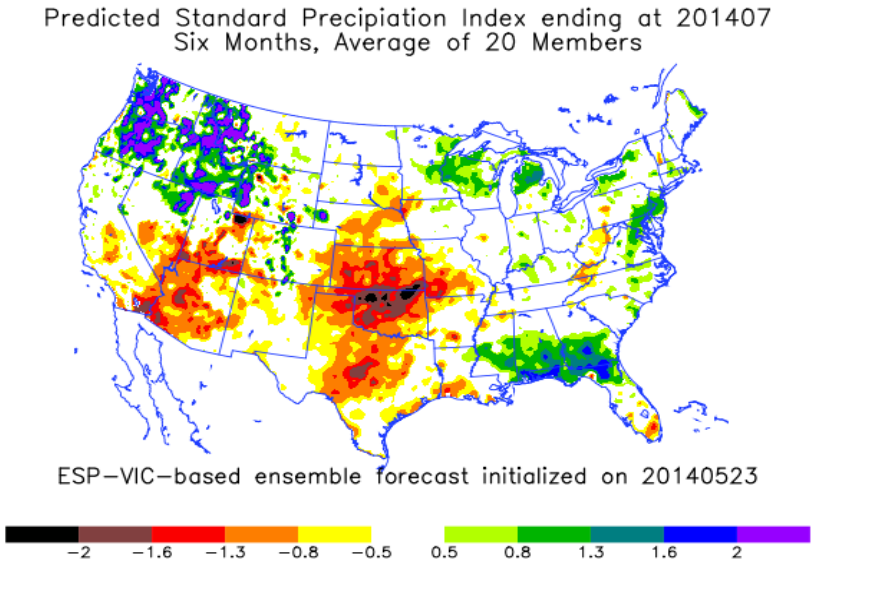
Drought Monitor 07/13



2014 forecast July SPI6

Prediction from April fields





http://drought.geo.msu.edu/research/forecast/spi6.php

Summary and Implication:

- **Most of La Ninas do not lead to summer drought over SGP. Anomalous anticyclonic circulation in spring and resultant dry soil moisture anomalies appear to be critical in set the stage for summer drought over SC US.**

- **Strong spring soil moisture deficit can reduce convection, cloudiness and atmospheric humidity. The resultant increase of longwave cooling could have stronger contribution to the subsidence and mid-tropospheric high anomalies in spring than reduced rainfall latent heating. Such radiative feedback, along with soil moisture-rainfall feedbacks could further re-enforce the initial dry large-scale circulation and soil moisture anomalies, consequently remain dry memory from spring to summer.**

- **Empirical model hindcasts show better skill than the baseline prediction of SGP. Thus, the spring to summer drought memory could provide additional predictability for summer drought relative to that provided by SSTA alone.**

Implication:

- ***More clear understanding on the causes of the spring anomalous circulation, and soil moisture and cloud/water vapor radiative feedbacks during spring to summer transition period may lead to significant improvement in seasonal prediction of summer drought in SGP.***